Improvement of the Three-Meter Ka-Band Inflatable Reflectarray Antenna

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Introduction An inflatable Ka-band (32 GHz) three-meter reflectarray [1] is being developed to achieve low mass and small launch-vehicle stowage volume for future deep-space spacecraft telecommunication antenna applications. The reflectarray's reflecting array surface, being a flat "natural" thin-membrane surface, is believed to have better reliability for long space missions than a curved thin membrane "non-natural" parabolic surface. A technology demonstration model of the inflatable reflectarray was previously developed [1,2] with excellent radiation pattern characteristics but poor aperture efficiency. This article presents the development of a second model that has significantly improved the efficiency from the previous 10% to 30%. This improvement was achieved primarily by a correct new element design. The previous inflatable mechanical structure, developed for ground demonstration purposes, has also been improved to approach being a space-flight design.

Description of the improvement The old unit of the 3m Ka-band inflatable reflectarray developed by JPL and ILC Dover, Inc., shown in Fig. 1, was tested in April 1999 at the compact range of Composite Optics Inc. (COI). Excellent radiation patterns, shown in Fig. 2, were measured with the expected beamwidth (0.22°), a very low sidelobe level (<-30dB within ±15°; <-50dB outside ±15°), and a very low cross-pol radiation (<-40dB within ±40°; <-50dB outside ±40°). These excellent pattern results indicate that the antenna has achieved the required surface flatness (0.5mm rms required; 0.2mm rms achieved). However, the measured antenna efficiency of this old unit was only 10% (50dB gain), which is far from the expected 40% (56dB gain). This antenna inefficiency was traced to a RF design flaw. All the patch elements on the reflectarray surface had very poor impedance matches to their phase-delay lines, as shown in Fig. 3. Each patch had an edge impedance of 300 ohms, while the phase-delay lines had impedances of only 100 ohms. Consequently, a 300-ohm patch connecting to a 100-ohm line resulted in a strong mismatch loss. In addition, the two delay lines were not correctly designed to become part of the resonating circuit of the patch, which did not allow the two orthogonal field components to resonate at the same frequency of 32 GHz.

This second iteration effort was initiated to correct the above design flaw. The new element design, that allowed the patch and the attached phase delay line to become a matched resonating circuit at 32 GHz, is shown in Fig. 4 and Fig. 5. The patch element has a nearly square shape with a corner-fed phase-delay line [3]. The corner feed generates the required two orthogonal polarization components from the patch, while the slightly rectangular shape (two unequal patch dimensions) provides the needed 90° phase differential for CP. The input impedance at the corner of the patch is about 150 ohms, which is still not quite matched to the 100-ohm phase-delay line. This is why the two additional stub tuners are attached toward the end of the phase-delay line to enhance the impedance matching and resonating circuit tuning. By calculating the RCS of the two orthogonal component fields and knowing the two fields are both resonating at 32 GHz with a 90° phase shift, a correct design has been achieved. Other than the different element designs, both the old and the new reflectarray units were designed with the same f/D ratio of 0.75, the same corrugated feed horn with edge taper of -9dB, and same element spacing with approximately 200,000 reflecting elements using variable rotation angles. The variable element rotation angles [4,5], shown in Fig. 5, are used to compensate for the different phase delays from the elements to the feed horn.

The mechanical design of the antenna has also been improved. The old unit, sketched in Fig. 6, has its inflatable tube shaped as a horseshoe and its feed supported by three asymmetrically located inflatable struts.

They are designed so as to minimize wrinkling of the aperture membrane when the antenna is deflated and rolled up. However, in doing so, the feed and its amplifiers are placed far away from the spacecraft, which is located just below the antenna. These amplifiers will be difficult to protect thermally from extremely cold temperature in space. To cure this temperature problem, the new antenna unit, shown in Fig. 7, is changed to a "movie screen" configuration, where the feed is offset located on the spacecraft and the reflectarray surface is deployed up and down independently from the feed by two inflatable tubes. In addition, the inflatable tubes in the new unit use space rigidizable material so that any small damage caused by micro-meteoroids will not impact the membrane performance and inflation air is no longer needed once the antenna is inflated. The particular space rigidizable material used here is the stretchable aluminum membrane [6]. A photo of the new antenna unit in movie screen configuration is shown in Fig. 8.

<u>Test results</u> The new antenna membrane using the old inflatable frame was tested at the COI's compact range for its RF performance. The antenna's surface flatness was first measured by the device illustrated in Fig. 9. A typical antenna pattern is given in Fig. 10 where it shows only a single high sidelobe/coma lobe at the level of -18dB below the main beam peak. Within ±10°, all the other sidelobes are below -23dB. Beyond ±10°, all sidelobes are below -50dB. The peak cross-pol level, within the main beam region, is below -28dB. Outside the main beam region, the cross-pol level is below -50dB, which is about -10dB lower than that shown in Fig.2 for the old unit. This extremely low cross-pol level indicates that very little mismatched energy is reflected from the membrane surface. Instead, most of the energy is re-radiated according to the design by the well-matched elements. The measured antenna peak gain is 54.4 dB. With the directivity of the aperture calculated to be 59.7dB, the antenna achieved an efficiency of 30%. The gain-versus-frequency measurement indicates a -3dB gain bandwidth of 470 MHz (the requirement is 500 MHz). The 3dB axial ratio bandwidth is 650 MHz, which is significantly larger than the single element's axial ratio bandwidth of 250 MHz. This is the result of the variable rotational technique used here, which is similar to that of the sequential rotation effect [7]. For the antenna efficiency, there is still room to improve the achieved 30% to the expected 40%. The areas for improvement will be discussed in the presentation.

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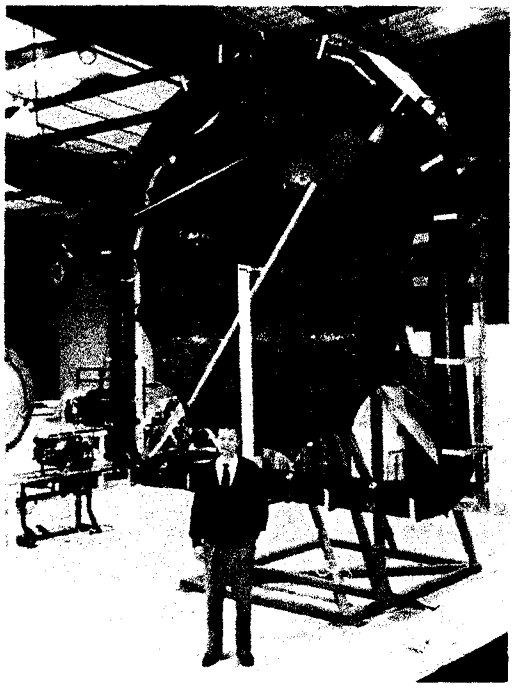

Figure 1. 3m Ka-band inflatable reflectarray antenna

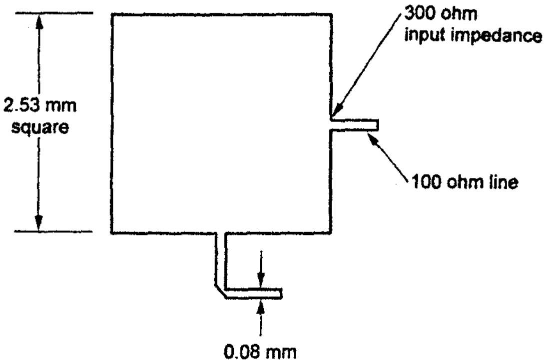

Figure 3. Old reflectarray patch element

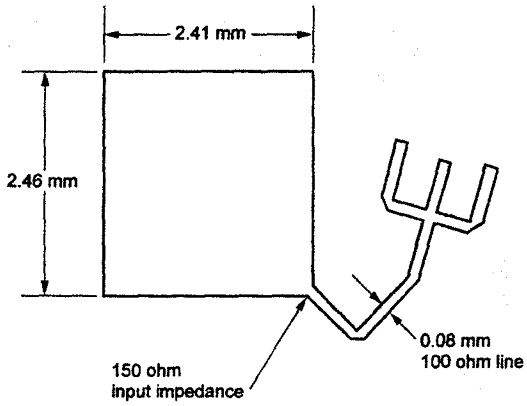

Figure 4. New reflectarray patch element

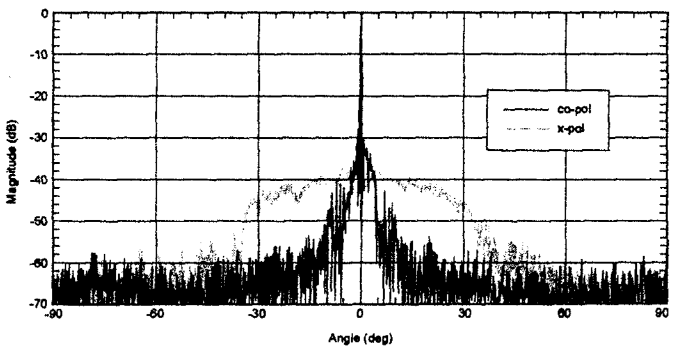

Figure 2. Measured pattern of the 3m inflatable reflectarray antenna. Vertical scale, 10dB/div; horizontal scale, 30deg/div.

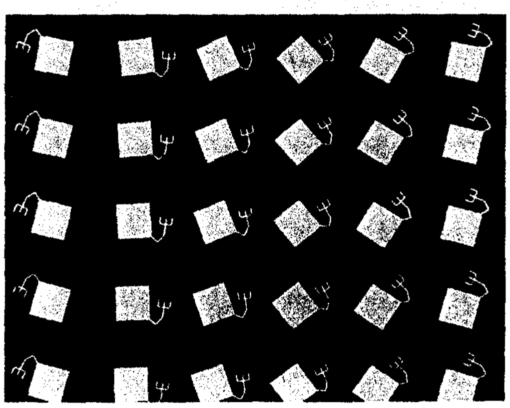

Figure 5. Photo of the new reflectarray elements showing the rotational technique

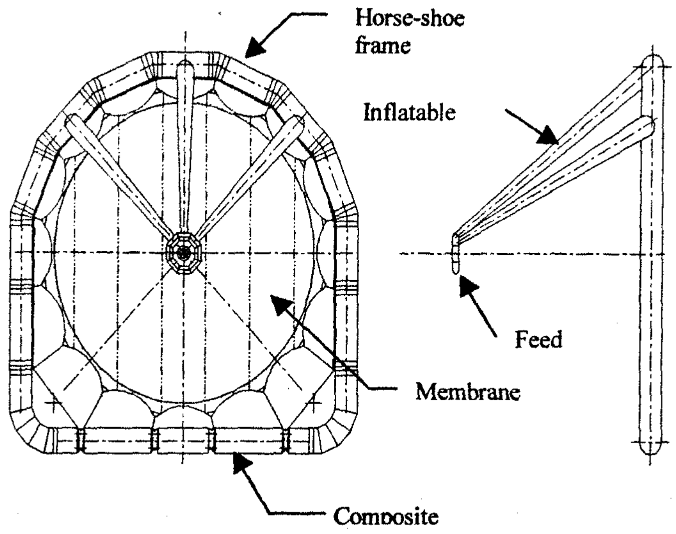

Figure 6. Old inflatable antenna structure with a horse-shoe shape

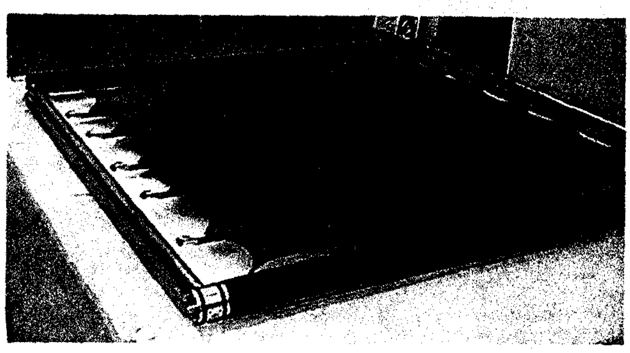

Figure 8. Photo of the new inflatable reflectarray with the "movie screen" configuration

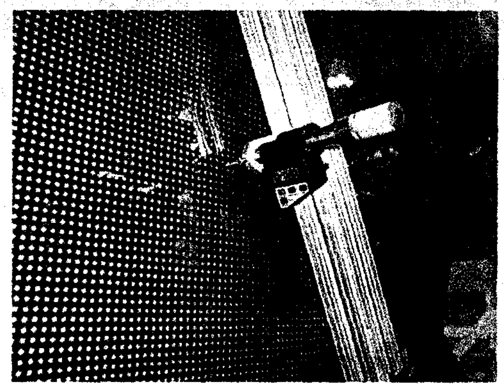

Figure 9. Close-up view of the membrane and the flatness measurement device

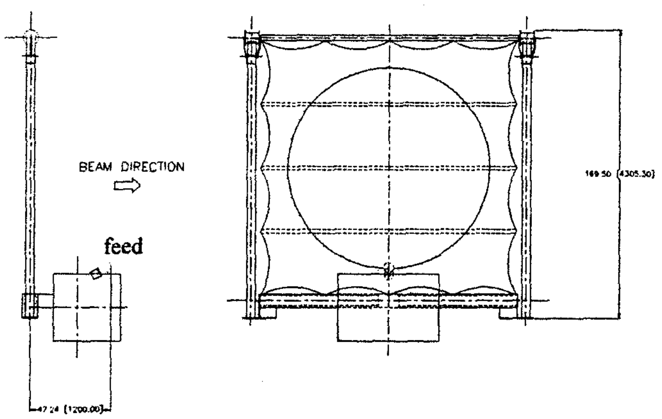

Figure 7. New inflatable antenna structure with "movie screen" configuration

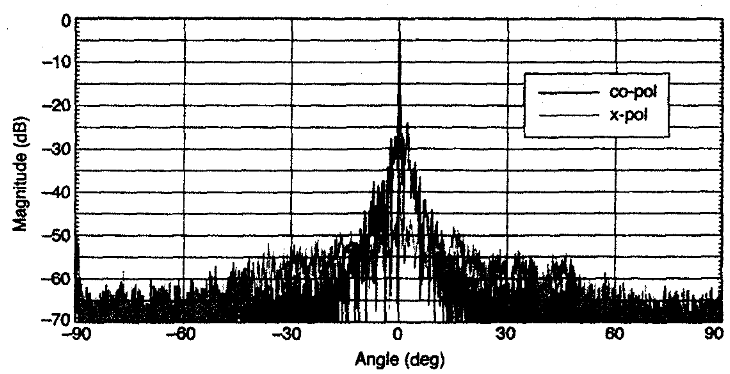

Figure 10. Measured pattern of the new Reflectarray antenna